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UNIFORMITY IN RAILWAY ROLLING STOCK.

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PART I.—LOCOMOTIVES AND CARS.

Few engineers, save those whose attention has been forced to the subject by experience, realize how much annoyance and increased cost result in the operating and repairing of Railway Rolling Stock, from lack of uniformity in their construction, nor how much efficiency and economy are promoted by building them with absolutely alike and interchangeable parts, so that duplicates can be kept on hand, which will be sure to fit, in case of breakages.

The master mechanics of our railroads, and especially the master car builders, have realized the importance of the subject, and have been discussing it for some years, and it is with the hope of forwarding somewhat the important reform which they are advocating, that the following plain relation of one experience of the Erie Railway has been prepared.

Until quite recently, American railroad companies, in purchasing their engines and cars, were content to make the most broad and general specifications. They specified the diameter and stroke of the cylinder, the size of the wheels and boilers, sometimes even the weight for the locomotives ; for cars, they mentioned the dimensions of the sills and of the wheels, axles and journals, stated that the materials must be good, and the workmanship first-class ; and left the design and the details to the contractors and builders.

The result was that there were about as many designs for engines and cars, as there were shops in the country. More, in fact, as each shop experimented at the expense of its patrons, and introduced whatever new designs it considered improvements upon its former plans.

This was a natural and useful stage of development, for although it produced considerable diversity of practice, the various builders, competing in design, as well as in prices and workmanship, were constantly introducing improvements, and gaining valuable experience. It is probably largely due to this competition in design that the American locomotive of to-day requires fewer days' work to build it and to keep it in repair than any other of equal power in the world.

When, however, a railroad company desired to preserve uniformity in its cars and engines, it was virtually compelled to buy them all of one maker, and this was open to the objection that the company could never feel quite sure that it was obtaining the lowest competitive prices, and also that it had sometimes to wait for many months until its favorite shop could fill its orders.

Most companies were therefore often compelled by their necessities to buy engines and cars from several builders, and thus to introduce many types and designs upon their line. This had been the case with at least one American trunk line.

In 1874, there were upon the line of the Erie Railway (now the New York, Lake Erie and Western Railroad) 469 locomotives. These comprised no less than 83 different types of engines, among which were scattered the following numbers of different styles of parts, which, being peculiarly exposed to breakage, required duplicates to be kept on hand :

70	different	styles of	cylinders.
14	"	"	crank axles.
17	"	"	smoke-stacks.

41	different styles of	front end doors.
25	" "	driving-wheel centres.
71	" "	" " boxes.
50	" "	parallel rods.
42	" "	driving-wheel springs.
32	" "	eccentrics.
25	" "	links.

Those engineers who have had experience in repairs of machinery will appreciate what stacks of duplicate parts, and what forests of patterns, to say nothing of the confusion and annoyance, these figures represent. To those who have not such experience, some figures will be given further on which will indicate what economy even a partial reform has accomplished.

In cars, the same wild diversity prevailed. In 1874 there were 11 744 cars upon the road, comprising no less than 230 different varieties, among which were found the following:

27	different styles of	drawheads.
19	" "	journal bearings.
53	" "	journal oil boxes.
52	" "	brake shoes.

Besides great divergencies in wheels, axles, trucks, framing and general design.

Of bolts and nuts, and their screw-thread connections—the things of all others which it is important should be interchangeable—there was an endless variety; but the Erie experience in this last respect was so peculiar and instructive that it will be treated separately in a subsequent part of this paper.

In 1876, the management determined to change the gauge from the mistaken width of 6 feet to the standard gauge of 4 feet 8½ inches, and to avail of that opportunity of reforming the great diversity and consequent expense in the styles of rolling stock above enumerated, by reducing them to a few standard types, during the process of narrowing them up, as well as in providing the additional equipment required by the change, and the consequent increase of traffic.

The engines were first taken in hand, and, curiously enough, investigation showed that the readiest way of diminishing the number of types of locomotives was to introduce a new type, that of the "Consolidation"

pattern, which being twice as powerful as those of the ordinary "American" pattern, then chiefly used upon the road, enabled each of the standard gauge "consolidation" engines to take the place of two of the old "American" broad gauge engines, and largely increased the train loads.

It was decided, therefore, to place a number of "Consolidation" engines on the road, and in order to secure the best design, the master mechanic and the acting superintendent of motive power visited the various lines upon which such engines were working, examined the different patterns, and then consulted the father of Consolidation locomotives, Mr. A. Mitchell, Superintendent of the Wyoming Division of the Lehigh Valley Railroad, who made the first designs for such an engine in 1865, and succeeded in having it built, notwithstanding the adverse opinions of several locomotive builders, to whom the design had been submitted.

This done, having gathered all the data, drawings and information which could be obtained, a design was next made in the draughting office of the chief shop of the company at Susquehanna, for a "Consolidation" engine, to conform to the general Erie practice as to style of wheel centres, driving-boxes and bearings, rods and rod brasses, guides, cross-heads, taper of bolts, tender journal-boxes and bearings, and various other details which could be made interchangeable with those of other existing engines of different classes.

This design comprises 100 sheets of large drawing paper, upon which are shown some 200 different drawings, with full dimensions of every part noted thereon, and is accompanied by a specification of 22 pages, describing in detail the materials to be used, the tests which they shall undergo, and the way in which the work is to be done.

Having thus carefully matured a design, and described it in minute detail, it was expected that all the engines built under it would be exactly alike, and with absolutely interchangeable parts; and in 1877 the road began the construction of six "Consolidation" locomotives in its own shops, while it gave a contract for five to one firm of locomotive builders, and of five more to another.

The first difficulty encountered was to maintain the integrity of the design. Each of the locomotive builders thought that the locomotives would be much better if made to conform with *their* practice as to details, and accordingly proposed some changes, those of one builder being

different from those of the other. Some of the employees of the road also suggested alterations as the work progressed, which would in their judgment make the engines far more efficient.

The management, however, set its face like a flint against any changes, and in due time the locomotives were completed, placed upon the road, and have done excellent service ever since.

It was thought at first that these 16 engines were quite interchangeable, but in a few months this illusion was dispelled by an accident. One of them was caught in a butting collision, had its front end stove in, and was towed into the shop. As it was not otherwise injured, and another engine of the same class, but of different builder, was standing in the shop, awaiting some repairs likely to detain it a few days, it was attempted to take off the sound front end from the engine in the shop, to put it on the disabled engine, and to send the latter out again that afternoon.

You may imagine the resulting annoyance, when it was found that some of the bolt holes, around the periphery of the front end it was attempted to put on, mismatched the holes in the head of the disabled engine by $\frac{1}{8}$ of an inch, or just enough to prevent a good fit.

It was certain that the position and dimension of every hole had been carefully and accurately given on the drawings, but these failed to provide for the "personal equation" in doing the work. For that difference between men, which is such that no two mechanics are likely (without extraordinary care) to lay off the same distance, and especially a series of distances, exactly alike, even if they use the same foot rule and dividers, and the same method of marking reference points.

This experience set the master mechanic at work, taking pieces off from one engine and trying them upon others, and while the parts were found generally to conform and to be interchangeable, there were differences enough, caused by the "personal equation" which has been mentioned, to prevent some of them from making a good fit, without chipping or filing. They came together like the cheap Yankee clocks which were so well abused thirty years ago, instead of fitting, as they should, like the pieces of a modern watch.

Now, in operating locomotives, there are certain parts which are particularly liable to injury, and which require considerable time to make anew. It is a great advantage, therefore, to be able to keep duplicates of those parts on hand to replace a breakage, and these

should fit so closely as to enable the engine to resume its service at once. In order to provide for this, it was determined to furnish each contracting engine builder thereafter with a certain number of templates, in addition to the drawings and specifications, and this course has been followed for all the engines since put under contract, the original set of templates being kept in the company's own shop, and duplicates made as wanted. The list of these templates for a "Consolidation" locomotive is now as follows:

2	templates	for	drilling main frames.
2	"	"	laying out main frames, front end.
1	template	"	drilling cylinder face.
1	"	"	drilling steam-chest rest.
1	"	"	milling out cylinder ports.
1	"	"	drilling cylinder-heads.
1	"	"	drilling cross-heads.
1	"	"	drilling smoke arch-ring and front.
1	"	"	drilling stack-base and saddle.
1	"	"	drilling eccentrics.
1	"	"	drilling eccentric straps.
1	"	"	drill'ng piston spider and follower.
1	"	"	drilling back cylinder-head for guides.
1	"	"	planing back cylinder-head for guides.
1	"	"	drilling eccentric rod.
2	templates	"	planing cylinders.
2	"	"	laying out eccentrics.
2	"	"	turning eccentrics and straps.
1	template	"	drilling piston gland.
1	"	"	laying out bottom of pedestals.
1	"	"	laying out pedestal caps.
1	"	"	drilling pedestal caps.
1	"	"	drilling bottom front frames.
4	gauges	for	size of cylinders.
2	"	"	tail pieces.
2	"	"	cross-heads.
1	"	"	piston-rods.
2	"	"	main frames.
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Those templates which contain holes to be bored (and it will be noted that they form a majority), are provided with hardened steel bushings to guide the drill in boring, and these bushed templates present a further advantage, for they not only abolish the "personal equation" and prevent the mechanic from making mistakes, but they enable the builder to do the work with a cheaper class of workmen, and so diminish the cost of the locomotives.

There are now 108 "Consolidation" engines upon the road, and they are so exactly built that there is no difficulty in keeping duplicate parts on hand, which are sure to fit in case of accident, and thus bring about great savings of time and money.

A standard passenger engine of the "American" type of which some 20 have been placed upon the road, was similarly designed and covered by drawings, specifications and templates, and when the old broad gauge engines are worn out, there will probably be but 8 types of locomotives upon the line for the different classes of the service, instead of the 83 different varieties there were in 1874.

Even among these 8 types, all the parts which it is practicable to make alike will be interchangeable, such as throttles, throttle levers, oil cups, gauge cocks, tender axles and oil boxes, brasses, &c., &c., while moreover the driving-wheel boxes, driving springs, eccentrics, eccentric straps, links, front ends, smoke-stacks, rod brasses, crank-pins, guides, cross-heads and similar details will be interchangeable between several of the types.

Now the question will be asked, "How does this pay?" The best answer which can be given is the following table of cost of repairs for 7 years before and 5 years since 1876, when the system was inaugurated.

COST OF MAINTENANCE OF LOCOMOTIVES ON NEW YORK, LAKE ERIE AND WESTERN RAILROAD.

Year.	No. of Engines.	Mileage.	Repairs.	
			Cost.	Cost per 100 Miles.
1870	440	9 326 379	$1 312 798 33	$14 07
1871	475	10 579 766	945 207 63	8 93
1872	488	12 318 504	1 000 059 04	8 11
1873	497	13 697 460	1 096 755 36	8 00
1874	469	13 123 701	1 064 882 73	8 11
1875	461	12 762 870	807 719 85	6 33
1876	468	12 632 365	890 381 03	7 05
1877	466	12 587 998	621 543 89	4 94
1878	475	12 716 583	646 714 97	5 09
1879	504	14 174 523	539 638 97	3 80
1880	528	14 293 876	582 158 20	4 07
1881	544	15 905 282	630 181 43	3 96

This includes the building of new engines each year to replace those worn out and condemned.

From this it will be noticed that the cost per mile run has been reduced by more than fifty per cent., and that taking into account the material advance in labor and materials of the past two years, it is still diminishing. The average cost of repairs for the five years prior to 1875, was 9.17 cents per mile run, while for the past 5 years it was only 4.33 cents ; and this represents a saving of about $675 000 a year. Had the rate of cost of 1871 prevailed in 1881 the expenses of locomotive maintenance would have been $790 492 greater than they were.

The conclusion must not however be formed that all of the above savings, or even a major part of them, have resulted alone from the system above described. Much of the economy is doubtless due to other reforms introduced by the management of the road about the same time,

as well as to the better track consequent upon the substitution of steel for iron rails, to the decrease of wages, subsequent to the panic of 1873, and to the fact that many of the engines are new ; but a considerable part is certainly due to the adoption of rigid standards, and of interchangeable parts, and moreover a very considerable number of the old engines still remains, with all their imperfections, so that further benefits may be expected to result from the system, as it becomes extended in the future.

The same system has been adopted for cars ; careful drawings and specifications have been made for a standard passenger car, a standard box freight car, a stock car, a platform car and a coal gondola car, and all new equipment added is made rigidly to conform to these standards ; while it is also applied to all cars rebuilt to take the place of those condemned, as well, so far as possible, to the old cars in the process of reducing their trucks to the standard gauge.

This has wonderfully lessened the variety and amount of material which has to be kept on hand at the shops, to make good the wear and breakages, and very much expedited the performance while it lowered the cost of the work.

The resulting economy in car repairs and maintenance is shown upon the following table of cost for several years past.

COST OF MAINTENANCE OF CARS ON N. Y., L. E. & W. R. R.

YEAR.	Number of Passenger and Baggage Cars.	Cost of Repairs.	Cost per Car.	Number of Freight and Coal Cars.	Cost of Repairs.	Cost per Car.
1870..........	345	$340 215 54	$986 13	8 840	$778 105 12	$88 02
1871..........	356	287 925 31	808 78	9 779	944 181 72	96 55
1872..........	378	273 023 15	722 28	10 638	846 193 02	79 55
1873..........	375	274 082 45	730 89	10 373	906 020 96	87 34
1874..........	344	211 768 34	615 60	10 775	920 532 82	85 43
1875.....	358	250 967 91	701 02	11 274	861 447 18	76 41
1876..........	407	383 331 91	941 85	11 337	852 274 25	75 17
1877..........	401	153 601 49	383 04	11 298	725 877 39	64 25
1878..........	407	139 043 51	341 63	11 656	624 229 39	53 56
1879	396	145 421 76	367 23	17 567	639 491 54	36 40
1880..........	411	182 965 24	445 17	20 831	678 170 05	32 55
1881..........	410	259 771 70	633 59	23 309	797 033 45	34 19

Prior to 1875, the figures are compiled from the reports to the State Engineer. Subsequent years are taken from the reports of the Auditor N. Y., L. E. & W. R. R.

This is subject to the same qualifications as to the causes of the economy, which have been mentioned as applying to the repairs of locomotives, and to the further consideration that the freight equipment having been very largely increased during the last three years, doubled, in fact, the new cars are not yet sufficiently worn to require extensive repairs.

It will be noted that in freight car repairs the saving has amounted to about 60 per cent., while in passenger car repairs it is only about 40 per cent., chiefly in consequence, doubtless, of the much smaller proportion added. The average cost of car repairs for 5 years preceding 1875, was $771 42 per passenger car, and $87 19 per freight car. For the 5 years preceding the present year, it was $434 96 per passenger, and $40 92 per freight car; and these figures indicate an annual saving of about $136 000 for passenger, and $783 000 for freight equipment. Had the cost of 1871 prevailed in 1881, the expenses would have been $71 828 greater for passenger car maintenance, and $1 453 550 greater for that of the freight cars.

If even but 10 per cent. of these savings were due to the adoption of a rigid standard of uniformity, it would have richly repaid all the labor and care it has cost.

Part II.—Screw-Threads.

As American cars, apart from the trucks or running gear, chiefly consist of wood, and the various wooden parts are principally fastened together with bolts, the factor which becomes important in securing promptness and economy of repair, is that the threads upon the bolts, and those upon the nuts designed to go upon them, shall, for the same sizes, be a good fit, and absolutely uniform and interchangeable. Wood can be cut and fitted with ordinary tools, but a nut too small cannot be screwed up home, and if it be loose, it is pretty sure to rattle off.

In contracting for all new cars and engines, therefore, the New York, Lake Erie and Western Railroad carefully specified that the builders should exclusively furnish threads of the "United States" (or Franklin Institute) standard; but at the same time, the mechanical department thought it well to look at home, to see how the matter stood in its own shops.

In 1873, the road had nominally adopted the "United States" system and standard of screw-threads.* It had procured a number of sample taps and dies, and furnished a set to each shop, with instructions to reproduce them as required by the wearing out of the old sets.

In 1877, or only 4 years after the adoption of this standard upon the Erie Railway, it was discovered that nuts cut at some of its shops did not properly fit bolts of the same diameter cut at other shops. The matter was then throroughly investigated. A nut of each size was ordered cut at each shop, with the tap in common use, and supposed to be standard, and these nuts were sent to the firm of Pratt & Whitney, of Hartford, Connecticut, whose well known accuracy and efforts to maintain mechanical precision, gave assurance of thorough and correct results.

In their shop the corresponding bolt thread was reproduced by fitting a soft plug of Babbit metal to each nut. This was screwed in and out, being expanded if necessary by driving a steel mandril in a central hole left for that purpose until it fitted perfectly, and the plugs so obtained were used to make measurements of the screw-threads. Each nut was then cut open in the centre, and the half nut of each shop could then be tried upon the Babbit plug representing the bolt cut at another shop.

The result was surprising, and the plugs and half nuts presented a series of misfits which require to be seen to be appreciated. They can-

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* The "United States" system of screw-threads was devised in 1864 by Mr. William Sellers, for the Franklin Institute. It presents such excellent features that it has been adopted by the U. S. Government, by the Master Mechanics' Association, the Master Car Builders, and by railroad companies generally. Its guiding rules are as follows :

1°. The outside diameter of the threads vary by even fractions of inches.

2°. The pitch, or number of threads to the inch, vary with the diameter of the bolt in the following order :

UNITED STATES, OR FRANKLIN INSTITUTE STANDARD.

Diam. of Tap or Die,	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
No. of Threads to Inch,	20	18	16	14	13	12	11	11	10	10	9	9	8	7	7

Diam. of Tap or Die,	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4
No. of Threads to inch,	6	6	$5\frac{1}{2}$	5	5	$4\frac{1}{2}$	$4\frac{1}{2}$	4	4	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{4}$	3	3

3°. The depth of the thread is made equal to 0.65 of the pitch.

4°. The angles which all the threads make with each other is 60°.

5°. The top and bottom of the threads are bounded by flat surfaces (parallel with the body of the bolt), which are equal in length to ⅛ of the pitch.

not well be represented on paper, but an examination of the pieces reveals most serious differences.* Neither the diameters, nor the pitch, nor the depth of the thread, nor their angles, nor the flat surfaces were found to agree.

Even in the pitch, or number of threads to the inch, they do not agree. This was accounted for by the fact that some of the shops had sent nuts cut with the tap used for *engine* bolts, while they had another tap with a different number of threads to the inch for *car* bolts, though why they should differ, and how both could be the standard, is not so apparent.

The table on the following page exhibits the discrepancies which were found to exist in the two most important particulars of pitch and diameter, and its careful inspection is required in order to appreciate the divergencies it shows.

It will be noticed that almost all the diameters are different, and that *not one is right.* The sizes are given in 10000 of inches, and the errors vary from 17-10000 up to 550-10000, while every nut but one was found to be too large.

The fact was that each shop, in reproducing its taps and dies, had by more or less imperceptible degrees, departed from the original standard. The diameter had been increased, the depth and angle of the thread had been altered, the flat surfaces at the top and bottom had been curtailed, and the threads thus given more of a V-shape. Even where the right pitch had been used † it had been altered a little, and as was said before, and amply appears from an examination of the plugs and half nuts, a bolt cut at one shop was not properly fitted by a nut cut at another.

Having thus found out some of its own deficiencies, the mechanical department next sought for what comfort it could get from those of its neighbors. For this purpose 22 nuts, all nominally of ¾-inch diameter, were unscrewed from as many cars belonging to 16 different railroad companies. The result was indeed gratifying and instructive, and is shown upon the list, on page 304, of the sizes which were obtained.

* These plugs and half nuts have temporarily been deposited in the rooms of the Society for inspection.

† The nuts cut with a pitch differing from the U. S. Standard were intended to fit bolts on old locomotives built with the arbitrary and differing systems of threads formerly prevailiu

DIMENSIONS OF NUTS—ERIE RAILWAY.

Shop.	1 Inch.			⅞ Inch.			¾ Inch.			⅝ Inch.			½ Inch.		
	No. of Thread.	Diameter.	Difference.	No. of Thread.	Diameter.	Difference.	No. of Thread.	Diameter.	Difference.	No. of Thread.	Diameter.	Difference.	No. of Thread.	Diameter.	Difference.
Standard........	8	1.0000	......	9	0.8750		10	0.7500		11	0.6250		13	0.5000	
Jersey City.......	8	1.0040	0.0040	9	0.8780	0.0030	10	0.7530	0.0030	11	0.6280	0.0030	12	0.5025	0.0025
Eastern Car......	8	1.0340	0.0340	9	0.9100	0.0350	10	0.7815	0.0315	11	0.6575	0.0325	13	0.5320	0.0320
Port Jervis........	9	1.0082	0.0082	9	0.8880	0.0150	10	0.7620	0.0120	10	0.6370	0.0120	12	0.5102	0.0102
Susquehanna.....	8	1.0060	0.0060	9	0.8800	0.0050	10	0.7510	0.0010	11	0.6290	0.0040	13	0.5055	0.0055
Hornellsville.....	8	1.0017	0.0017	9	0.8875	0.0125	10	0.7535	0.0035	10	0.6190	0.0060	12	0.5020	0.0030
Buffalo Repair....	8	1.0017	0.0017	9	0.8870	0.0120	10	0.7550	0.0050	11	0.6275	Small. 0.0025	13	0.5085	0.0085
Buffalo Car.......	8	1.0550	0.0550	9	0.9215	0.0465	10	0.7890	0.0390	11	0.6565	0.0315	..	......	......
Elmira Car.......	8	1.0175	0.0175	9	9.9000	0.0225	10	0.7637	0.0137	11	0.6350	0.0100	13	0.5175	0.0175

Sizes of ¾-inch Nuts.

Owner of Car.	No. of Threads	Diameter.
Standard nut should be	10	0.7500
Lake Shore & Michigan Southern R.R.—1,	10	0.7815
" " " 2.	10	0.7637
" " " 3.	10	0.7815
New York Central & Hudson River R.R.—1.	10	0 7637
" " " " 2.	10	0.7890
Flint & Pere Marquette R.R.—1	10	0.7815
" " " 2.	10	0.7637
Lehigh Valley R.R., 1877	10	0.7815
Philadelphia & Reading R.R.	10	0.7637
Cleveland, Columbus & Cincinnati R.R.—1	10	0.7815
" " " 2.	10	0.7815
Erie Railway, 1876	10	0.7890
Michigan Central R.R.	10	0.7815
Grand Trunk Railway—1	10	0.7815
" " 2.	10	0.7815
Chicago & Northwestern R.R.	10	0.7815
Toledo, Peoria & Warsaw R.R.	10	0.7815
Chicago, Milwaukee & St. Paul R.R.	10	0.7815
Toledo, Wabash & Western R.R.	10	0.7815
Pekin, Lincoln & Decatur R.R.	10	0.7815
Cincinnati, Lafayette & Chicago R.R.	10	0.7815
North Pennsylvania R.R.	10	0.7815

It will again be noticed from this list, that not a single nut was found to be of the correct diameter, although there are but three different sizes. A greater number of sizes could probably have been found, by examining more cars, the above having been selected haphazard, but that was not what was being sought.

The object was to know how the sizes ran, and it will be seen that all the nuts were too large, both on foreign roads and in the Erie shops, with the single exception of one nut from the Hornellsville shop.

In fact, it was ascertained that the practice was all but universal of cutting nuts over size, especially for car work, and that the Erie Railway had merely followed the general drift in departing from the standard.

It was found that there were three reasons for this state of affairs.

1st. That the sizes of bolts on foreign cars were generally larger than the standard, and the Erie nuts had to be cut over size in order to fit them.

2d. That, as there were several different over sizes, the nuts were cut loose, so as to go on the larger bolts. This resulted in bad fits and much shaking off of nuts.

3d. That most of the iron delivered by the rolling mills was over size, and in order to avoid the expense of going over a bolt twice, in cutting the thread, the practice obtained of cutting all rough bolts over size.

Indeed, so universally had these causes operated, that in 1876, only 12 years after the making of the original standard of screw-threads, the makers of taps and dies systematically made them over size, and had even formulated a rule attempting to regulate this inaccuracy, that :

"Up to and including $\frac{5}{8}$-inch diameter, the size of nuts shall be $\frac{1}{64}$ over the standard. Above $\frac{5}{8}$-inch, they shall be $\frac{1}{32}$ large."

That is to say, a certain standard system was devised, it was nominally adopted by almost all the parties interested, including the railroads, and a rule was then straightway formulated to depart from that standard in one of its most important particulars.

It was stated by the makers of taps and dies that prior to the recent reform in this matter, due to the efforts of the master car builders, about three-fourths of their sales of taps and dies consisted of those which were over size.

Now, the effect of this practice was twofold, so far as car repairs were concerned :

First.—The roads did not adhere to the same amount of over size, as fully appears from the dimension of nuts on the Erie Railway, and on the several cars, a list of which has been given, and although the differences may be thought small, they are quite large enough either to prevent a nut from going on a bolt at all or to leave it so loose as easily to rattle off.

When, therefore, a car arrived at a shop, with a nut gone, instead of putting on at once a standard nut, investigation had to be made as to the amount of over size used by the road or firm which built the car. If this differed from the particular inaccuracy practiced by the road doing the repairs, recourse must needs be had to the "old nut barrel," and here the trouble commenced.

"The old nut barrel" contained the many hundred specimens of nuts of different sizes which had been taken off from foreign cars. They were picked over and tried on, one at a time, with whatever patience or profanity the workman might be master of, until one was found to fit. This fit was almost sure to be a loose one, but the nut was, nevertheless, screwed up, and the car sent off with a fastening tolerably certain to work off, and to give some other road a chance to overhaul its "old nut barrel." If no nut was found to go on; if a bad fit could not be made in that way, the old bolt was knocked out and a new bolt (cut to a different over size) was inserted, to plague somebody else. Thus much of the car repairs took tenfold the time and caused tenfold the expense which would have been incurred if all the roads had rigidly adhered to the standard which they had nominally adopted, and made their screw-threads of exact sizes.

The second effect of over sizes was that the roads paid for more iron than they ordered or required. The rolling mills all delivered iron over size, and upon being consulted, their managers said that they did so because they thought that their customers preferred it. That there was some little additional trouble in rolling iron to exact sizes, and that it was safer to make it a little large, and that as they charged for actual weights, by the pound, there was no objection so far as they were concerned in making the bars as large as would be acceptable to the customers.

Several lots of iron were then measured at the Erie shops, and they were found to run from $\frac{1}{32}$ to $\frac{3}{64}$ of an inch over size. The over weight seemed to average about $8\frac{1}{2}$ per cent. Now, the Erie Railway had during the

year 1877, cut about 700 000 pounds of round iron into bolts, and if the over weight be assumed at 5 per cent. (instead of 8½ per cent.), it had probably paid for some 35 000 pounds of iron, worth, at three cents a pound, $1 050 more than it required.

Moreover, it appeared by investigation, that it was costing $1 822 a year to maintain this bad system of inaccuracy by making the taps and dies in the company's own shops, and that these could be purchased for less money from makers who made a specialty of maintaining uniform accuracy.

It then had become so clear that only annoyance, bad workmanship, and expense resulted from the continuance of the existing practice of making the taps and dies in the company's own shops, that it was determined to discontinue this and to come down to exact standard sizes as soon as possible. Accordingly, in October, 1878, the following order was issued:

"In order to preserve uniformity in screw-threads the following rules shall hereafter govern:

"1st. All new taps, master-taps, and such dies as are not attached to machines, required for regular use shall hereafter be procured upon requisitions instead of being made at each shop as wanted. The workman hitherto doing such work shall be relieved or assigned to other duties.

"Taps for special work may either be made or ordered, as circumstances will warrant.

"New taps and dies shall, however, be ordered only when actually required for use, and the present supply shall be utilized until worn out.

"2d. All new engines and cars shall be constructed with screw-threads, bolt heads, and nuts in exact conformity with the United States standard known as the 'Franklin Institute' or 'Sellers'' system.

"3d. All iron and steel received for bolts shall be carefully inspected to make sure that it does not run over or under size, and bars involving double cutting, or too small, shall be rejected.

"4th. All new bolts, &c., for the repair of the existing rolling stock, shall be cut to the exact standard sizes, except in cases where great expense or inconvenience would result therefrom.

"5th. Such of the existing taps and dies as may be found to differ from the exact standard, shall be used only to duplicate existing threads

in repairs of the rolling stock, and only so far as necessary to prevent waste or extra expense."

But the Erie experience did not stop here. It next obtained some lots of taps and dies from different makers, both those which were supposed to be of exact size and those which were made over size, in accordance with the curious rule which has been mentioned. These lots were compared, and it was found that the taps and dies made by different makers did not agree as to size.

These several makers had been saying for some time that the road could not hope to maintain standard sizes in its own shops. That absolute accuracy required special appliances, which these makers had obtained at great cost, and that it was, therefore, better to buy all taps and dies of them. Now, it was discovered that the product of different makers did not coincide, and that if the road purchased of one firm and wanted to preserve a standard, it could not purchase of the other.

Next, the cause of this difference was inquired into, and the makers of taps and dies said that they did not know. One firm stated that it had spent two years in time, and over $10,000 in money, in obtaining the exact measurement of an inch, and its multiples and fractions, from the standard yard, deposited at Washington. The other firm said that they had most faithfully copied the original gauges recognized as correct, and made for the United States Government several years before, by a most careful and accurate mechanic of Massachusetts, named Fox; and that there was a standard set in the Brooklyn Navy Yard, to witness their assertion.

Here was at last a gleam of light. The inquiry led back to the original standard. The makers of these uninterchangeable taps and dies were accordingly told to bring down their standard gauges to the Brooklyn Navy Yard, and they would all be compared together.

This was done, and the result was apparently to make confusion worse confounded. The three sets of gauges did not agree with each other. It is true that the differences were not great, being at most 1-1000 of an inch, and such that while they could be measured by instruments of precision, they cannot well be exhibited in a table; but the fact remained that the gauges were not interchangeable.

Perhaps some engineers, accustomed to measure to 1-100 of a foot, will say that 1-1000 of an inch is not much of a distance; and doubtless in some locations it may be neglected altogether. Yet if they will

examine the ½-inch gauge and the two plugs, one exactly ½-inch in diameter, and the other just 1-1000 of an inch smaller, made by Pratt & Whitney for Mr. Forney of the *Railroad Gazette*, and kindly loaned by him; they will find that this 1-1000 of an inch makes just the difference between a close fit amd a loose fit.

It may be said further, with respect to the comparison of the three sets of gauges, that those of the firm which had obtained its own measurements from the standard yard at Washington, were found to be the most accurate; that next to these were the gauges of the other firm, and worst of all were those of the Government at the Navy Yard. This was accounted for by the fact, that being made of soft iron they had worn in using, and the effect of such wear, in maintaining standard size, will be further alluded to hereafter. The two tap and die making firms had been careful to case harden their gauges, and in one case they had been made adjustable to take up possible wear.

Having thus traced the differences connected with the screw-threads, through their range of many inaccuracies, even to a difference of original standards of measurements, the next step was to apply a remedy.

For this purpose a general meeting of the Master Car Builders' Association was held in New York, on the 18th of December, 1879, to which were invited Mr. William Sellers, the originator of the American system of screw-threads, and the various manufacturers of taps and dies.

At this meeting the existing difficulties were explained, and the question was fully discussed.

It appeared that the master car builders had all encountered the trouble, annoyance and expense resulting from the lack of uniformity in screw threads, and were confident that a general reform in this respect would save hundreds of thousands of dollars annually to the railroads of the country.

On the other hand the makers of taps and dies explained how great were the difficulties of maintaining, even the partial accuracy which they had secured, described their processes, and expressed their willingness to encounter further expense to secure greater correctness.

Mr. Sellers, being asked for his advice, gave it at length. He described the methods which had been employed in the shops of William Sellers & Co., to secure accuracy, and to inspect the dimensions of screw threads. He stated that his firm had found it more accurate and cheaper

to buy their taps and dies than to continue their manufacture, and gave some very valuable hints as to the best methods to follow in future.

In consequence of this advice it was decided by the master car builders to abandon the use of "over sizes" completely in screw-threads, and to come down to the exact standard, as soon as possible. A committee was subsequently appointed, with Mr. M. N. Forney as chairman, which reported at the meeting just held, June 15, 1882, at which a resolution was adopted commending the reform to such railroads as have not yet carried it out.

The makers of taps and dies, on their side, agreed to make their gauges agree, and to use absolutely the same standards in manufacturing their goods.

The care of verifying and making these standards was entrusted to the firm of Pratt & Whitney, and it has now spent two years, and a good deal of money, in revising its former measurements, in devising and building, with the aid of Professor W. A. Rogers, of the Cambridge Observatory, a new measuring machine to establish a standard inch, and in making accurate sets of gauges, which will be placed on the market in a month or two.

The difficulties they encountered in their pursuit of the standard inch will be found partially described in Mr. Forney's report to the master car builders.

But after the standard gauges have been made there remain two difficulties to be overcome:

The first arises from the expansion and contraction of steel in tempering. After a screw tap has been made of soft steel, it is quite accurate, but before it can be used it requires hardening. In this process it becomes more or less distorted, so that with all possible care the taps of the same makers are not absolutely uniform. This was tested on the Erie Railway. A dozen taps were obtained from one maker, and a nut was tapped with each. They were then interchanged, and it was found that there were differences enough to make the taps run loose through some nuts and tight through others. This might be overcome by grinding the taps after hardening, but the cost would be prohibitory, and would be rendered nugatory by the second difficulty.

This difficulty results from the wear of the tap or the die in actual use. They may be absolutely correct when put in the machine, but with the first nut or bolt they begin to wear, and although that wear is min-

utely small it becomes appreciable in time, so that a nut cut with an old tap will hardly go on a bolt cut with an old die, and so tempt the workman to resort to over sizes and bad fits.

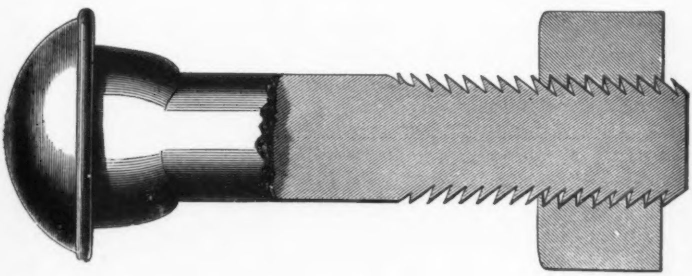
Impressed with these difficulties inventors have devised many ingenious contrivances to overcome their results.

It would carry us much too far to review the large family of "nut locks," which have been proposed, experimented on and discarded. Some few are effective, but they chiefly apply to track bolts, and are beyond the scope of this paper.

It is preferred to call attention to three attempts to make the bolt and nut adjust themselves to each other, so as to produce a good fit, even if differing in original size.

The first is an English invention, that of Mr. Ibbotson. It consists in boring out the outer end of the nut, and filling it with a soft metal, through which the bolt may thread its way, forcing the metal into a tight fit.

The second is the "grip bolt" of the Harvey Manufacturing Co., of which a cut is given herewith. In this, the thread of the bolt is under-

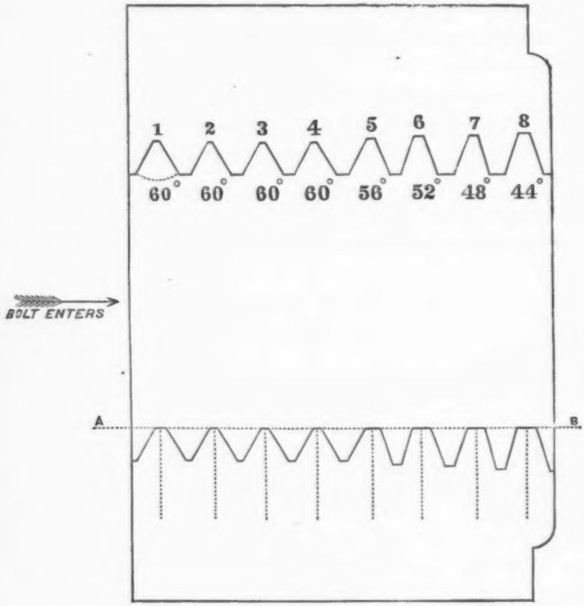


cut at an acute angle, while the nut is cut with the same pitch (or number of threads per inch) but with perpendicular surfaces on the inner edge of the threads. The effect of this is that when the nut is screwed on, it "upsets" the ends of the threads on the bolt and presses them into a close fit, and thus prevents the tendency to loosen.

This, however, is open to the objection that it introduces a new style and system of threads, and that these threads, being cut to thin edges, are apt to be injured.

Mr. Harvey has, therefore, been led to invent the third device, in which the Sellers system of screw-threads is retained for the bolt, but the nut is so shaped as to plow its way into a close fit.

This is effected by cutting the first half of the nut to correspond with the standard thread of the bolt (making an easy fit), and by gradually changing the angle of the remaining threads through the second half of the nut, as shown upon the drawing herewith.* Thus the threads which are at an angle of 60 degrees with each other through the first half of the



* Harvey Mfg. Co. Pat. Spiral Wedge or Self-fitting Nut (head section). A to B is straight line across the tops of the threads, showing that the nut is not a tapered one.

Threads numbered 1 to 4 are United States Standard, having an angle of 60°.

From Nos. 5 to 8 the angle of the thread is constantly changing, *i. e.*, it is growing more and more acute.

To preserve the standard number of threads to the inch, the tops of the threads are thickened as the threads become more acute.

These more acute threads are also deepened, giving room for the expansion of the bolt threads (of an angle of 60°) when this nut, with threads gradually growing more and more acute, is "wedged" into, or plows its way through them.

nut, become at an angle of 45 degrees at the rear end of the same nut, the intervening portion being "a spiral wedge, which, by means of the starting threads upon the nut, is made to enter the grooves of the bolt thread, and to compress and displace the metal." The threads upon the rear half of the nut being gradually deepened to make room for the flowing metal.

The effect of screwing such a nut on a bolt, is to pinch and squeeze the threads of the bolt, engaging (at a different angle) those in the rear half of the nut, to cause the metal to flow, and to force the bolt and nut to adjust themselves to each other. This undoubtedly secures tight fits, even when the bolts and nuts are cut to appreciably different sizes.

Whether this system will produce in practical use the excellent results which it promises, whether the straining of the metal beyond the limit of elasticity, to cause it to flow, will weaken the threads, or whether the threads will be so distorted when the nut has to be screwed on and off a number of times, as to eventually result in loose fits, experience and time must tell.

The object has been to point out the great economy and advantages which result in constructing railway rolling stock with absolutely interchangeable parts; the mechanical difficulties which stand in the way, and the devices which have been introduced to overcome them. It is hoped that these will engage the attention of this society, and that its members will join in promoting the reform of past inaccuracies.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

CCXLV.

(Vol. XI.—September, 1882.)

THE HUDSON RIVER TUNNEL.

By WILLIAM SOOY SMITH, Member A. S. C. E.

READ AT THE ANNUAL CONVENTION, MAY 19, 1882.

WITH DISCUSSION

By WILLIAM H. PAINE, Vice-President A. S. C. E.

In order to appreciate fully the necessity and value of a means of crossing the Hudson River from the New Jersey side to New York City, which shall be safe, quick, economical and uninterrupted, it is necessary to bear in mind the following facts and considerations:

1st. The greatness of the traffic flowing to New York from all the country west and south of it, and the prospective increase of this traffic.

2d. With but one exception, the railroads leading to New York from the West and South terminate on the west bank of the Hudson.

3d. The present means of crossing by ferry is, in comparison with unobstructed passage of railroad trains under or over the river, inconvenient, slow, expensive, and at times uncertain.

A bridge across the river is not to be thought of at any point opposite the island on which the city stands, and if one were built farther up the river it would be practically inaccessible to all but one of the railroads now requiring a better crossing.

It must therefore appear that tunnels under the river afford the only available means of providing for all the railroads now built and terminating on the New Jersey shore opposite New York, and for all that may hereafter be built, a suitable passage for their traffic into the city.

By a suitable passage is here meant tunnels of ample capacity, so well and strongly built as to command the fullest confidence of the public, thoroughly lighted and ventilated, and terminating in commodious stations, conveniently located.

The Hudson River, at the point at which the tunnel under it is now in course of construction, is one mile wide from bulkhead wall to bulkhead wall.

Throughout a distance of one thousand feet frcm the New Jersey shore its depth is about ten feet at mean low tide.

The water deepens from this point by a quite regular slope of the bottom through a distance of three thousand two hundred feet to the middle of the channel, which is sixty-two feet in depth at mean low tide. This depth decreases quite rapidly to twenty-five feet at the pier-head on the New York side, which depth is carried to within a few feet of the bulkhead wall. These figures are not exact, but they are sufficiently so to give a proper understanding of the tunnel plans, and they cannot be made more full and precise without going into unnecessary detail.

The bottom consists of silt (which will be more accuratey described hereafter) throughout the entire width of the river. Underlying this silt on the New York side there is a bed of coarse sand twenty feet in thickness, and, below this, a stratum of coarse gravel. These strata being at the depth of the tunnel as planned and partly executed, the work on this side has to be partly executed in them.

From a point six hundred feet out from the bulkhead wall on the New York side to a point sixteen hundred feet from the same, the silt is underlaid by rock in place at a depth of from eighty to ninety feet below mean low water. This rock is covered with silt, the least thick-

ness of which is twenty-eight feet. Farther west, the borings made at each one hundred feet have not penetrated through the silt, although they have been made, at points to a depth considerably over one hundred feet. This silt is the material carried down and deposited by the river. A sample was taken from the heading when it was 400 feet out from the New Jersey shore, and at a depth of sixty feet below water surface, and, after drying, analyzed by Professor Albert Leeds, of the Stevens Institute, with the following result:

	Per cent.
Combined water	5.13
Combined silica	58.95
Free silica, or quartz	10.32
Protoxide of manganese	10.95
Alumina	15.14
Protoxide of iron	3.28
Sesquioxide of iron	1.38
Lime	2.88
Magnesia	1.50
Sodium combined as chloride	0.23
Chlorine existing in the form of chloride	0.38
Sulphuric acid	Trace
Titanic acid	Trace

These materials make up a stuff which is very finely comminuted, and, when containing one-third water, as it does when exposed to air pressure in the headings of the tunnel, it is compact, tenacious, and about of the consistency of putty as used by the glaziers. In this condition it weighs 109 lbs. per cubic foot. It is almost impervious to air and water, and makes an excellent puddling material, though from the quantity of sand it contains it yields readily to a current of water, and behaves under its action much like quicksand. It shrinks greatly in drying, and where it has been exposed for a length of time to air pressure, the water is slowly pressed back through and out of it, and it then cracks and falls down. Its resistance to displacement at a depth of sixty feet below water surface (ten feet water and fifty feet silt) was found by experiment to be 5 580 pounds per square foot. Under the river and through the materials described the Hudson River Tunnel has been planned and is in course of construction. The tunnel proper extends from the foot of Fif-

teenth street, Jersey City, to the foot of Morton street, New York, and is 5 400 feet in length from shaft to shaft. The bottom of the tunnel on the New Jersey side is 45 feet below mean low water surface, and on the New York side it is 65 feet below the same. It descends with grades of from two to three per cent. from both extremities to the deepest point under the channel, where, as planned, it reaches a depth of 109 feet, which it carries through a level section 500 feet in length.

On the New Jersey side the work was commenced by sinking a brick shaft, circular in form. An attempt was then made to go out of this shaft with a single tunnel large enough to accommodate a double-track railroad. This effort failed. It was then determined to build two single-tracked tunnels instead of one for a double track. A temporary entrance was cut through the side of the shaft, and work commenced on the north tunnel, which was carried out between two and three hundred feet. An effort was then made to work back and connect the tunnels permanently with the shaft. This effort also failed. A caisson was then sunk between the shaft and the end of the completed portion of the north tunnel. Connection was then made between the caisson and the north tunnel, and the south tunnel was started out of the same caisson. Both tunnels were afterward pushed forward several hundred feet before the permanent connection was made between the caisson and shaft. This was done in November and December last. These tunnels are about thirty feet apart. They are nearly circular in cross-section, having a vertical diameter of 18 feet, and horizontal diameter of 16 feet, in the clear. They are each surrounded by a wrought-iron shell, conisting of plates ¼-inch thick, united by inside flanges and bolts. Inside of this shell there is a brick lining in all the tunnel completed to about the 1st of last April two feet thick, but it has recently been increased to 2 feet 6 inches, to provide for the greater pressure due to the increased depth reached. The south tunnel has been completed on the New Jersey side to a distance of 562 feet from the west side of the shaft, and the north tunnel is out on the same side to a distance of about 1 000 feet from the same point.

During the construction of bulkheads, and making connections between caisson and shaft, and re-installation of plant on the New Jersey side, the rate of progress was 53 feet of single tunnel finished per month for eight months, through a great deal of very soft material that had been disturbed by the construction of docks, etc.

Since that time, during the last two months, the rate, in much better material, has been about 90 feet per month, and it is confidently expected that this rate can be increased to 100 feet per month.

The mode of construction is as follows (See Plate XXXI): A wrought-iron tube called a pilot 5 feet 6 inches in diameter, consisting of plates ¼-inch thick united by interior flanges and bolts is first carried forward into the heading with its axis preferably about two feet above that of the tunnel.

This is done by excavating a cut into the heading wide enough for the insertion of one of the pilot plates and deep enough to enable a workman to put this plate in position at the top where it is held by bracing from the bottom of the cut.

Another cut is then made on one side of the first one and a second plate of the pilot is put in place and bolted to the first pilot plate. A third pilot plate is put in place in the same manner on the opposite side of the first. Cuts are successively made and plates put in position on each side and brought down in the right curve to make up a complete section of the pilot until this first ring or section is complete. Another ring is then put in, in advance of this in the same way, and united by bolts to the one first completed. The pilot is thus advanced ring by ring until it is carried from 20 to 30 feet beyond the face of the heading. The plates of the main shell of the tunnel are then put in and connected with each other in the same way; each plate of the main shell being braced from the pilot by radial bracing. When the excavation has been sufficiently advanced in this way, a 10 feet section is lined with the brick work; meantime the pilot and shell are carried forward without interruption. The rear end of the pilot is braced from the finished brick-work and the front end is so far advanced into the material of the heading that it becomes fixed. The pilot thus serves as a rigid centre from which the main shell can be conveniently held by bracing, and it serves as a bridge from which the unequal pressures occuring along its length can be held and resisted. In soft and varying material it is of manifest advantage. Where the character of the material is better, the pilot is not required and a considerable part of the tunnel has been built without it and probably more rapidly than it could have been done with it.

The use of compressed air as an indispensable auxiliary in the construction of the Hudson tunnel marks an era in tunnel construction.

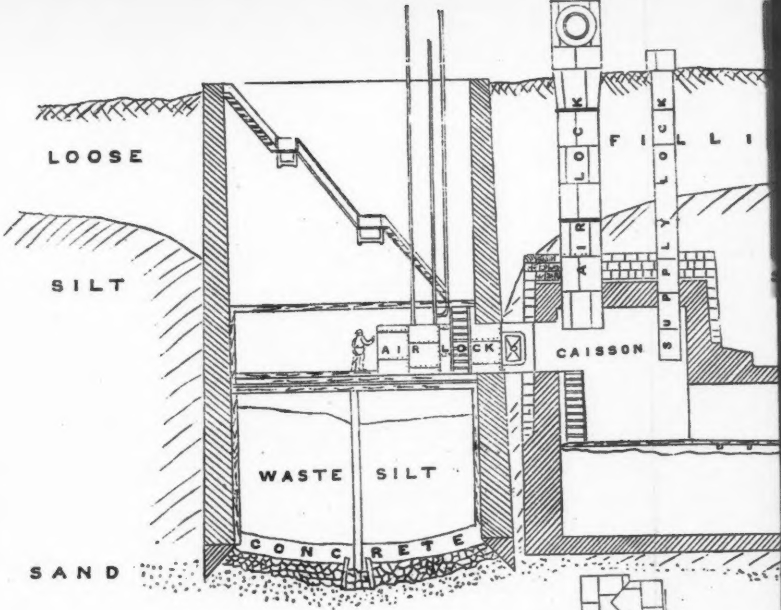
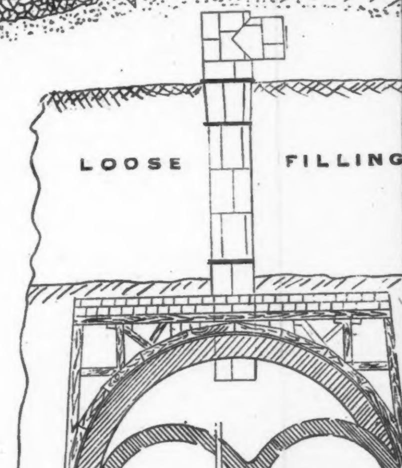


PLATE XXXI.
TRANS. AM. SOC. CIV. ENGR'S.
VOL. XI. No. CCXLV.
SMITH ON
HUDSON RIVER TUNNEL.



SECTION
N & S THROUGH
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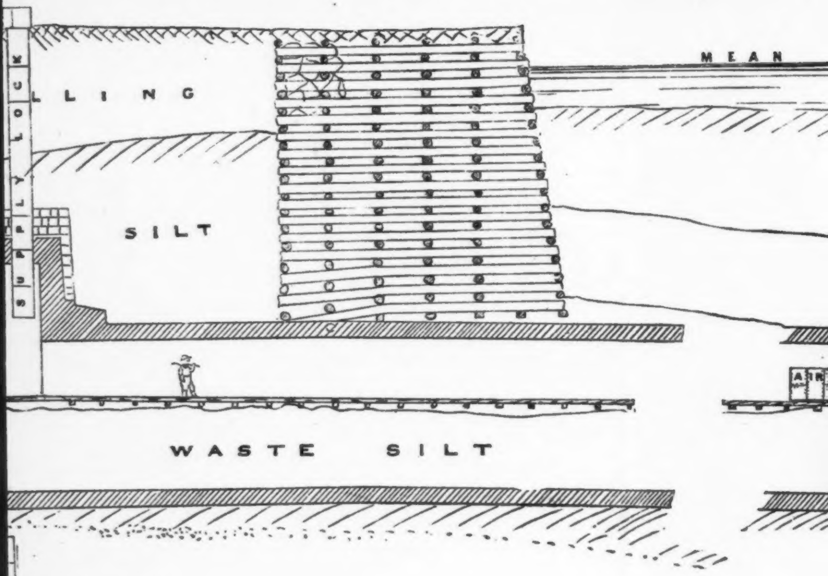


N
UGH
CAISSON

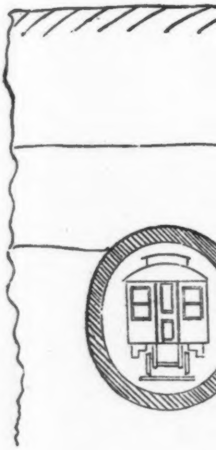
HUDSON RIVER TUNNEL

JERSEY SIDE

W. Sooy Smith & Son.

Chief Engineers.

Scale 20′ = 1″



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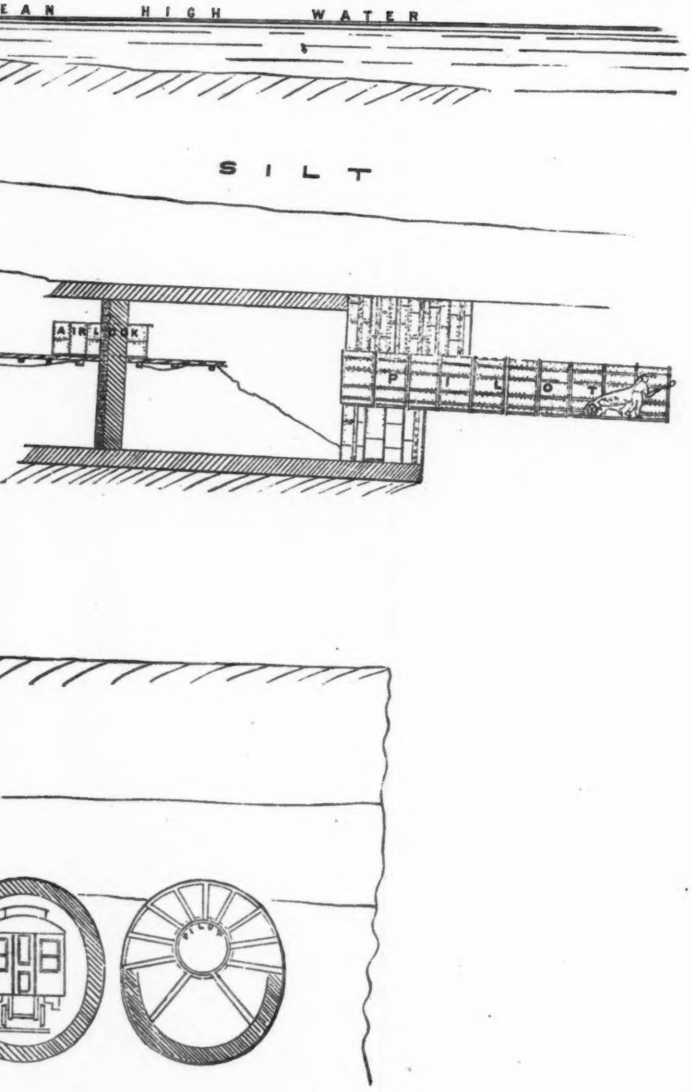


SECTIONS
UNNEL MPLETED
TUNNEL IN CONSTRUCTION

The idea of so using it is by no means new. As long ago as 1830, an English patent was issued to Sir Thomas Cochrane, for this application of compressed air. And in his specification filed on the 20th of April, 1831, he fully describes the entire process now used in the construction of the Hudson River Tunnel, so far as the use of compressed air is concerned, including descriptions of the air-locks and bulkheads employed. Mr. Chesbrough and other American Engineers gave much study to the same subject, years ago, and as early as 1870, the writer filed a caveat in the United States Patent Office for a pneumatic apparatus for tunneling. A small tunnel was actually constructed by the pneumatic process at Antwerp and finished about three years ago.

But while these things are true and interesting as matters of history, it is altogether likely that D. C. Haskin, the projector of the Hudson River Tunnel and its constructor, thus far, knew nothing of them, and that they therefore do not detract from the credit due him as an original inventor.

The manner of using compressed air as applied in the construction of the work under consideration, may be very briefly explained. An air-lock was first inserted in the wall of the shaft projecting through it and into the outside material. Compressed air was forced into this lock, the door in its advanced end was opened and the excavation of the material commenced. As the excavation proceeded, the air forced in aided the plates and bracing employed to hold the materials in position and to keep the water out. Without pausing to describe the accidents which occurred, we may simply say that the excavation has been carried forward in this way ever since. At first the whole space inside the tunnels was kept filled with compressed air. When they were built out so far that the leakage became troublesome, and the pressure needed to keep the water out at the deepest points too great to be safely applied to the roof of the tunnels in their highest parts, it became necessary to build air-tight bulkheads in each of the tunnels, so that the air-chambers in the two were independent of each other, and of the portions of the completed tunnels in rear of the bulkheads. These bulkheads were then built; they are brick walls four feet thick backed by solid walls of timber 12 inches thick and strongly braced with timber braces let into the brick lining of the tunnel. There are two air-locks placed in each bulkhead, each of which will contain all the workmen employed at any one time in advance of it. One of these air-locks is designed to be kept

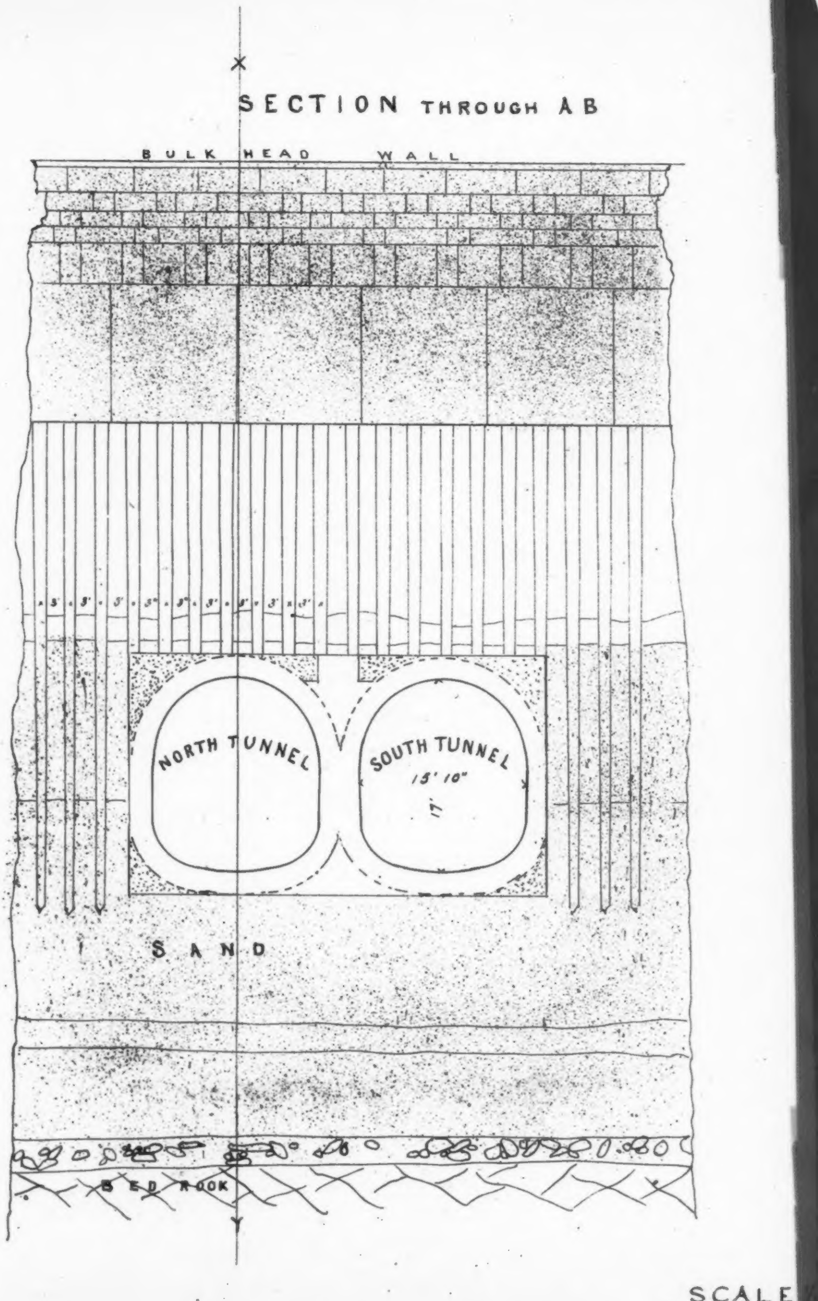
open toward the heading at all times, to provide a place of refuge for the men in case of necessity.

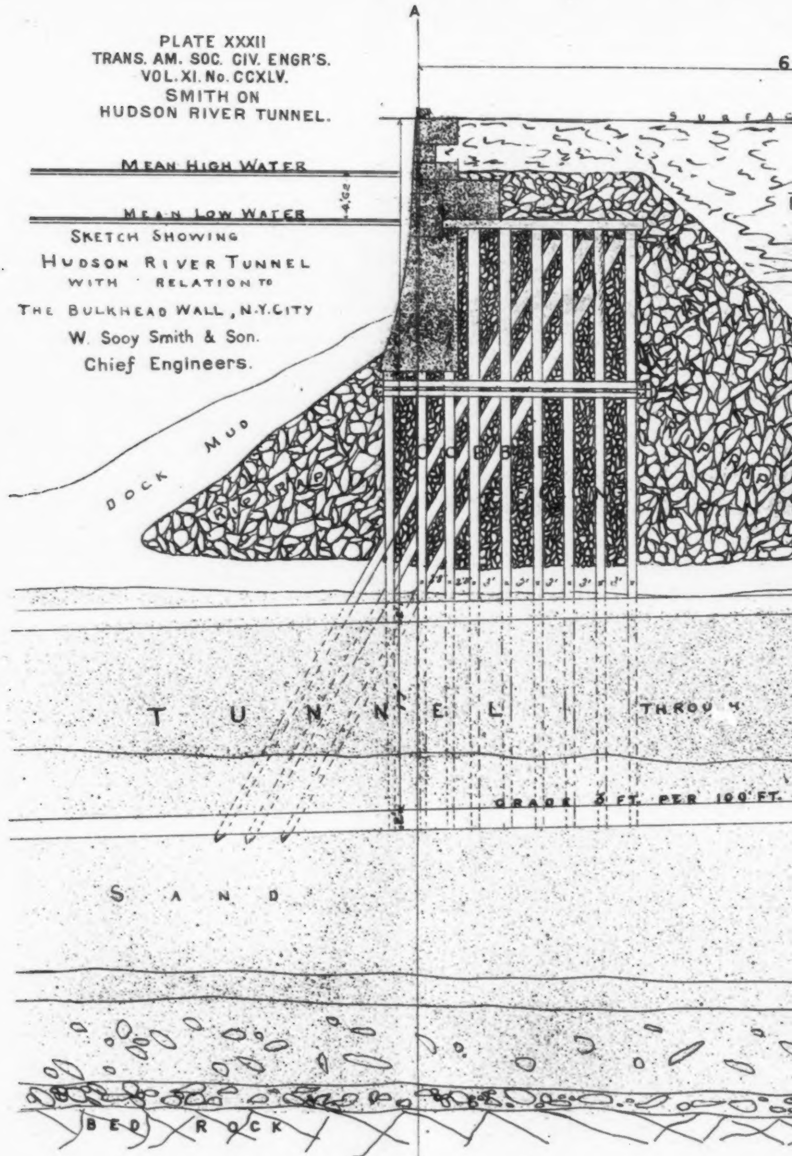
The movement of the materials in which the work is going on, is so slow, even when the air pressure is greatly reduced or entirely removed, that the men have ample time to avail themselves of the means provided for their escape to the rear of the bulkheads into the completed parts of the tunnels. All chance of the silt or water entering these parts of the work, is prevented by the bulkheads, which are air-tight, and of course, water-tight. Recently a second bulkhead with but one air-lock has been constructed in the north tunnel on the New Jersey side, 280 feet in advance of the first one.

Besides the additional safety afforded by two air-locks, the greater facility they afford for passing men and materials through the bulkheads —in the opinion of the writer—more than compensates for the additional expense involved.

The difference in density of the outer atmosphere and the compressed air at the heading is divided by the present arrangement in the north tunnel between the two chambers, one between the two bulkheads, and the other in advance of the second one ; so that the workmen in going into the heading, are not subjected to the whole change at once.

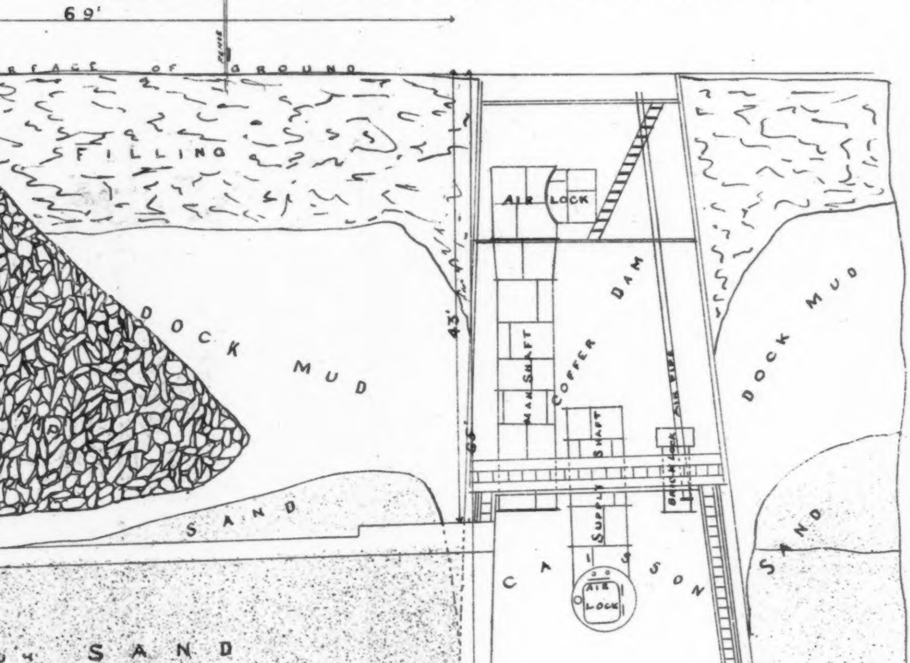
It is claimed that this will reduce the injurious effects of condensed air at high tension, but this remains to be proven by the results. On the New York side a caisson has been sunk to the required depth of $55\frac{5}{10}$ feet below mean low water, and an opening cut through it, and the north tunnel commenced. The accompanying Plates XXXII and XXXIII will show many of the details of this work. The caisson was sunk through made earth, piles, sand, gravel and boulders, with rather less than the usual hindrances, though it had to be very carefully done owing to the proximity of the bulkhead wall on one side and a 12-feet sewer on the other, and but fifteen feet away. The materials excavated were used to load the caisson while sinking, and in addition to this, railroad iron and bricks were piled upon its deck to increase the load to the necessary amount, 2 100 net tons, in addition to the weight of caisson (400 tons), to overcome friction and the upward pressure of the compressed air in the working chamber. When the caisson had reached the requisite depth, an invert was put in by carrying iron plates from the sides of the caisson down in the curve desired for the invert ; the brick work was then laid on these plates. After the


SECTION THROUGH AB
BULK HEAD WALL
NORTH TUNNEL
SOUTH TUNNEL
15' 10"
17'
SAND
BED ROCK
SCALE
MAY 2



SCALE 1/16 IN. TO 1 FOOT
MAY 2º 1882.

SECTION THROUGH CENTRE OF NORTH TUNNEL ON XY



invert was completed, and fitted with three stand pipes connected by a main trunk from which water could be pumped in large quantity if necessary by means of centrifugal pumps, an opening was cut through the side of the caisson and the north tunnel commenced. Doubts had been entertained by the writer and others as to the advisability of attempting to use the same process on the New York side which had been so successfully employed on the New Jersey side. The materials were known to be very different, and it was by no means certain that the method could be made to succeed. Not that it was deemed impossible, but the difficulties apprehended were of such a formidable nature that attention was directed very naturally to other methods which seemed more promising as to economical and practical results. It was feared that the sand and gravel through which the work has to be carried might not hold air sufficiently to keep the water out. To this it was replied that pumps could be employed to take care of whatever water might enter against the resistance offered by the compressed air. At all events, the work was commenced to test the matter practically before changing the plan of operations. When the caisson had been cut through, it was found that the disturbance of the surrounding materials which had taken place during the sinking of the caisson, had caused the silt to come down from above along the side of the caisson, where it formed an impervious envelope which aided the first operations essentially. The first plates of the main shell of the tunnel were put in with very little trouble. Indeed no extraordinary difficulty was encountered until the top plates had been carried out ten feet from the caisson, and the side plates several feet down from the top. As the area of the face of the heading increased, the leakage of air so increased that an attempt was made to cover the face with an air-tight timber bulkhead smeared with silt. This having failed, resort was had to iron plates for this bulkhead, made similar to the plates of the shell, only plain instead of curved, and much smaller. It was found that the area of sand exposed, through which the air escaped, must be kept small, not to exceed 12 feet if possible, and that all other surfaces of the excvaation must be made air-tight by an impervious covering. Great efforts were made to dry the material by pumping, but these failed. Water continued to come in, bringing sand with it. At length the air escaped through the sand to such an extent that the pressure left was not sufficient to keep the water out, and it flowed in, filling the excavation and the caisson, bringing in a large quantity of sand and forcing the

plates of the shell in on one side 16 inches. The air pressure was again restored, the opening stopped, and the work of putting in plates resumed. By proceeding very slowly, and exposing a very small surface at any time, the first ten feet ring of plates was at last completed, and this ring bricked up. The bulkhead has since been opened at the top and work commenced on the second ten feet ring. It is hoped that as the work proceeds further from the caisson the materials will be found in better condition, so that the work can be prosecuted more rapidly and economically. If the covering of silt overlying the sand and gravel becomes continuous over the work, offering no apertures through which the air forced into the tunnel can escape, or if the sand met with shall contain enough clay to make it hold air well, the extra difficulties will be much diminished, if they do not entirely disappear, but thus far they exist as was anticipated. The writer favors the construction of the tunnel from the New York caisson to a point beyond the deep water channel, by means of caissons sunk from the surface after a system fully worked out by him in the year 1876, and proposed for the construction of a tunnel under the Detroit river, at the City of Detroit; or by means of a movable caisson, by means of which section after section of the tunnel can be built and connected. If the tunnels can be carried out beyond the bulkhead wall by the present method, it is very desirable that they should be, as the sinking of caissons from the surface through this wall would be expensive, even if the privilege of doing so could be obtained, which is, perhaps, doubtful.

In view of the magnitude of the work, its very great value when done, and the novelty of the processes employed in its construction, there is, perhaps, no more important or interesting engineering work now in progress than the Hudson River Tunnel. The projectors of the work have completed so much of it already as to fully demonstrate the practicability of its construction. It is only necessary, 1st, that the plan should now be fully matured after careful study of the work as a whole, to avoid difficulties which might prove very expensive if not insurmountable; 2d, that the money needed shall be provided; and, 3d, that the actual execution of the work shall be prudently, economically and energetically directed and controlled.

It is a work which constantly demands the exercise of the very best engineering talent, supplemented by courage and skill on the part of the foremen and workmen, and by the good judgment and drive of the

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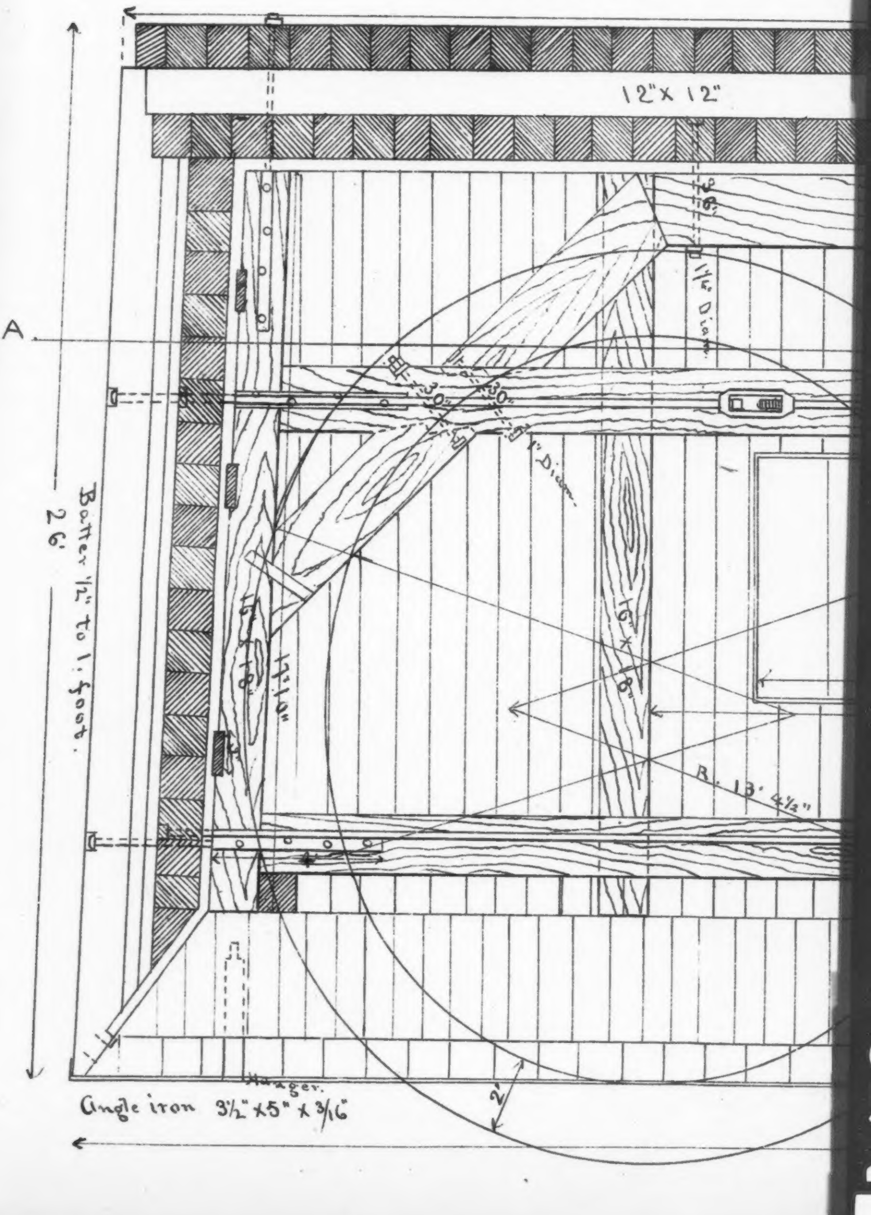
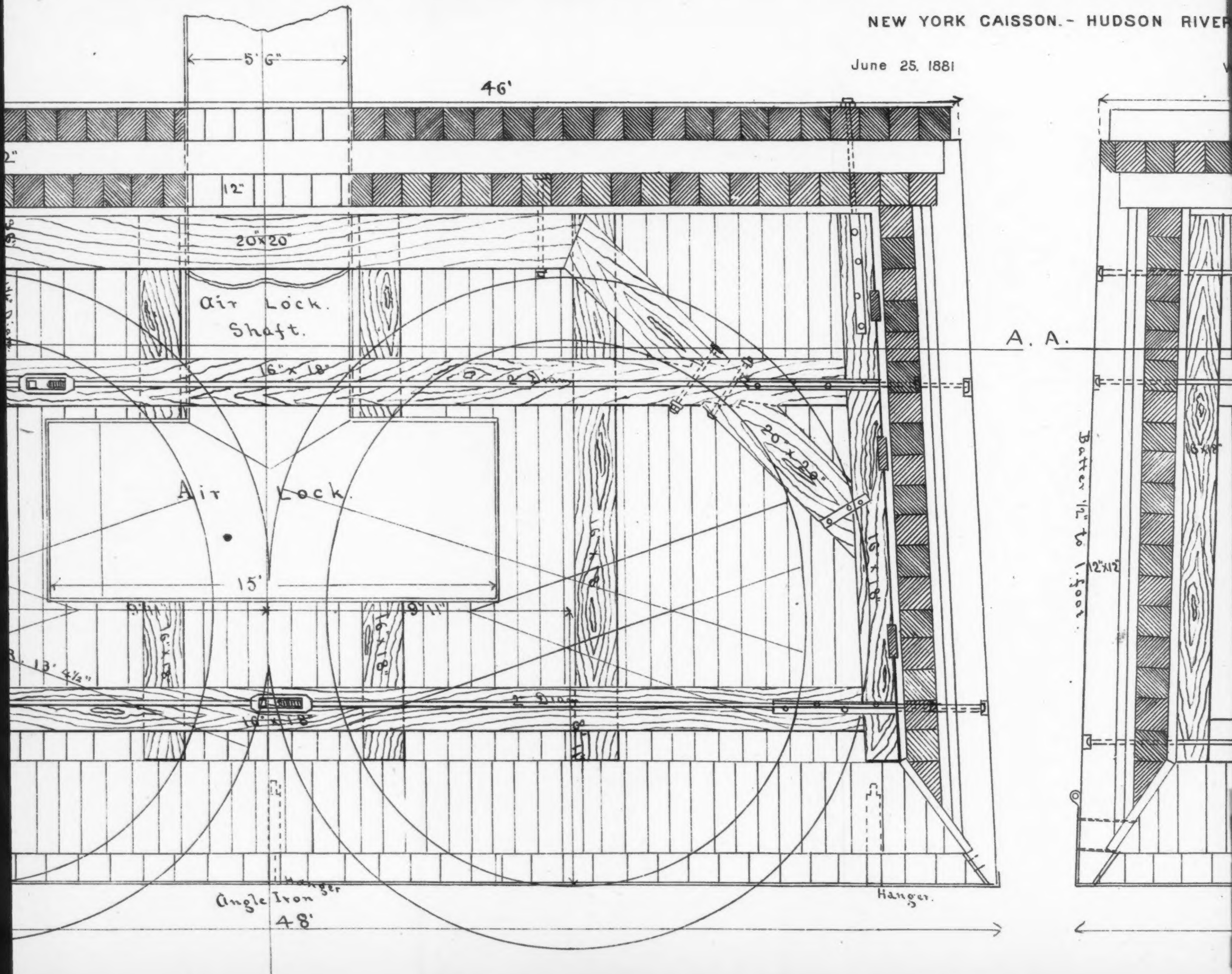
PLATE XXXIII
TRANS. AM. SOC. CIV. ENGR'S.
VOL. XI. No. CCXLV.
SMITH ON
HUDSON RIVER TUNNEL.



ongitudinal Section thro. B.B.

NEW YORK CAISSON.- HUDSON RIVER

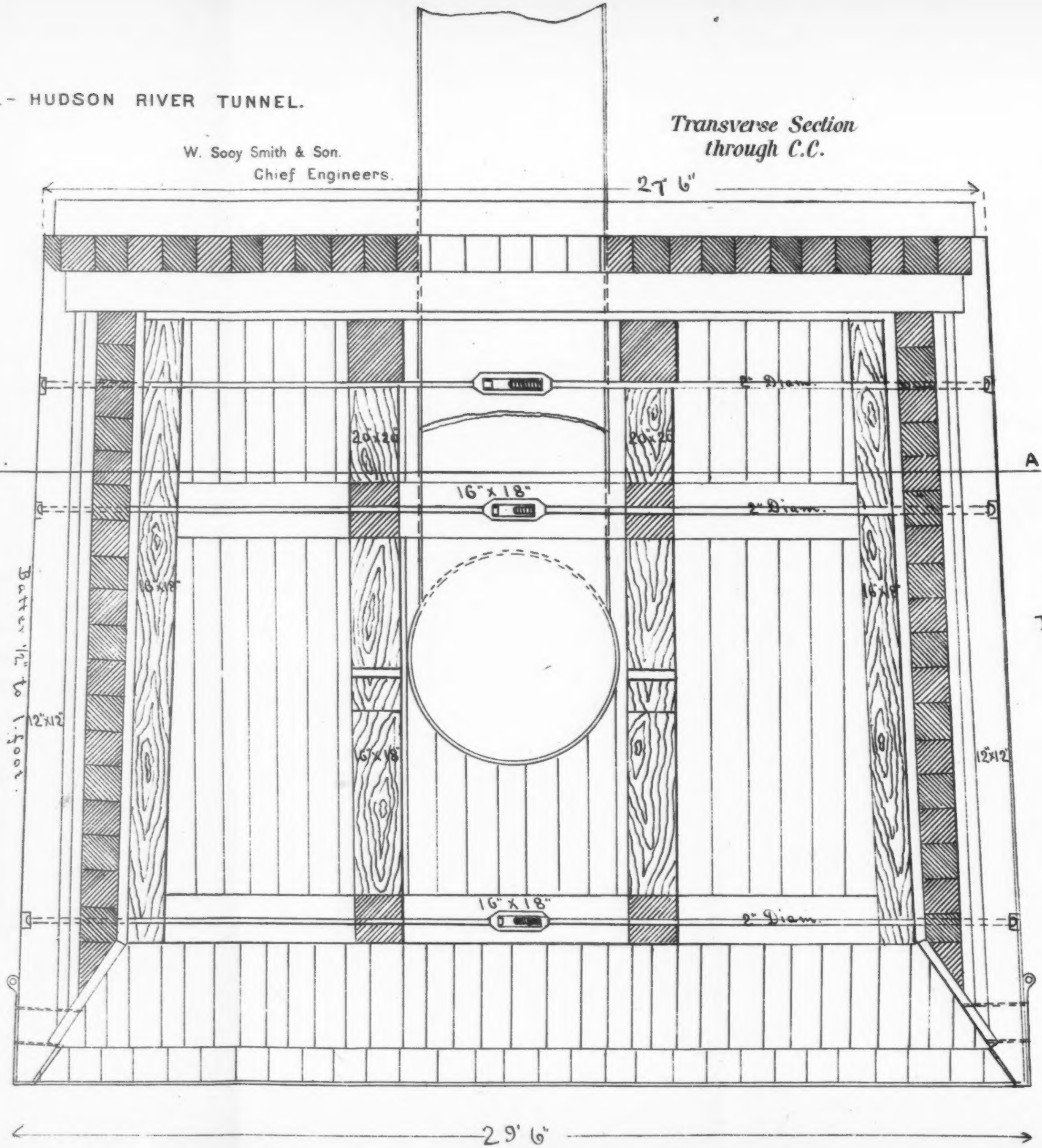
June 25. 1881



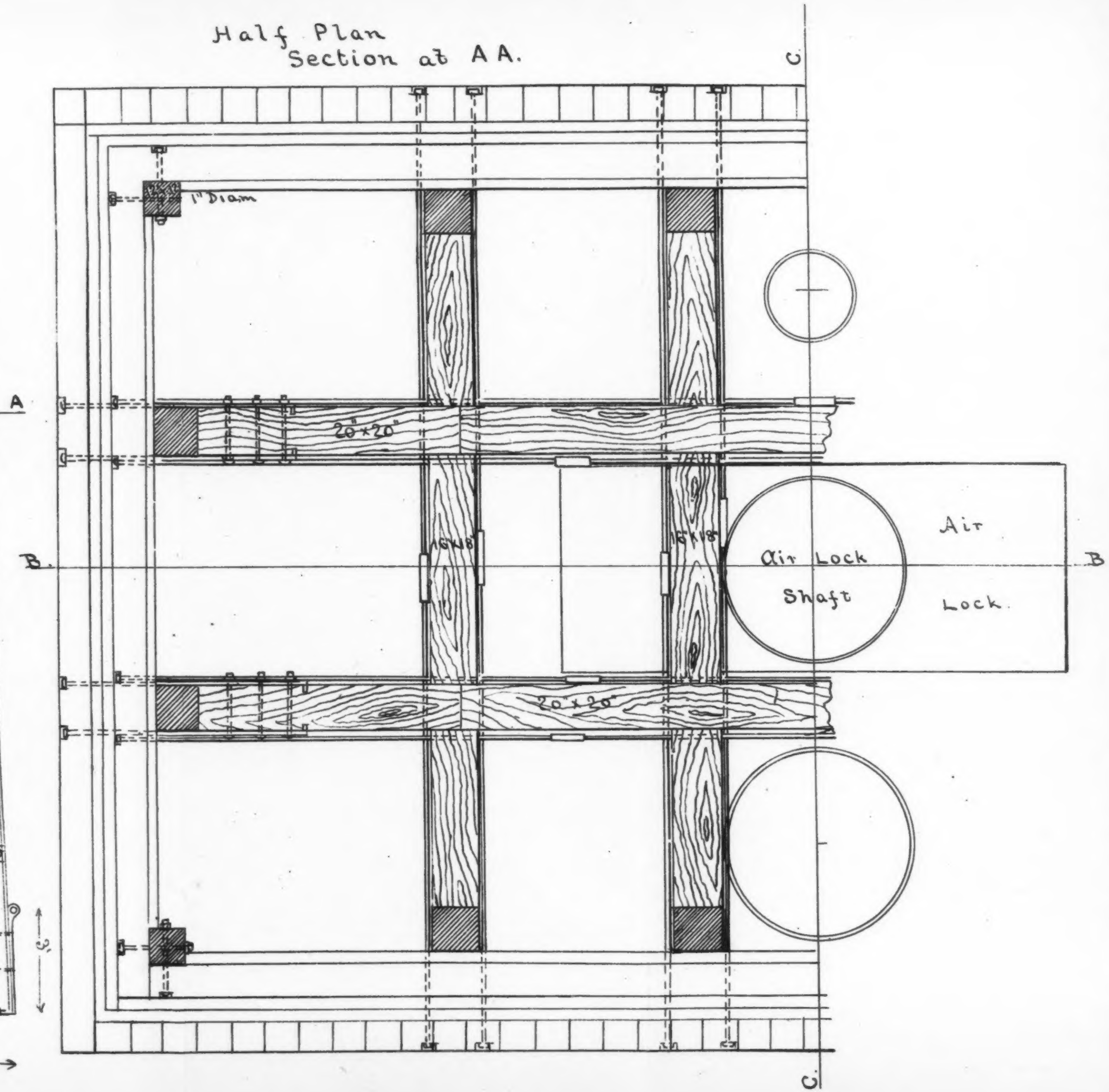
ON.- HUDSON RIVER TUNNEL.

W. Sooy Smith & Son.
Chief Engineers.

Transverse Section through C.C.



Half Plan
Section at AA.



contractor and the pecuniary strength, pluck and liberality of the men who furnish the money required. With these the work can be pushed along steadily to completion without more than the ordinary risks and contingencies which attend all great subaqueous undertakings. It is now placed fairly in the list of legitimate enterprises, lifted out of that of projected or experimental undertakings, by the actual execution of a considerable portion of the work. And it will be so considered henceforth by civil engineers who are best prepared to understand it as a work to be accomplished ; and by enlightened and farseeing capitalists, who will appreciate its value when done. It is also time that the City of New York should recognize the great value of this subterranean channel for its business with the western and southern country tributary to it, and grant every privilege and facility which can hasten its completion.

It will be far more valuable, less objectionable and probably no more costly than the entrance into the city to the Grand Central Depot on Fourth avenue.

It has progressed so far already as to justify the expectation that it will move on to completion with no more than the ordinary hindrances and delays, and, when done, prove a lasting benefit to the City of New York, and to all the country from which it draws its great and increasing business.

Discussion by Wm. H. Paine, Vice-President, A. S. C. E.

Mr. Chairman,—I rise to correct an impression that is abroad to the effect that whatever of success has attended this work has been achieved by going contrary to the advice and without the aid of engineers, which is not a fact.

The credit for the accomplishment of that portion of the work that has been successfully done is largely due to the engineers who have been connected with or advised in regard to it.

Great credit is due Mr. Haskin. The idea of using compressed air was original with him and the faith he had in it was not derived from the opinions of others.

It is true that Lord Corcoran as early as 1830 proposed using compressed air in tunneling and devised arrangements embodying the principal features of Mr. Haskin's plan, going still further and introducing a water shaft, such as was used in the East River Bridge caissons.

But we do not learn that Lord Corcoran ever made any practical use

of his ideas. And I have reason to know that Mr. Haskin had never heard of Lord Corcoran's inventions prior to making his own plans.

Great credit is also due Mr. Haskin for the boldness, persistence and energy displayed in this great work. His unbounded faith in compressed air has caused him to make most thorough trial of it and has thereby evolved some most useful and practical facts both in the direction of encouragement and warning.

Engineers have rendered most valuable service by indicating means adequate to accomplish desired ends, and by somewhat modifying the early announced policy of never looking ahead for, or anticipating difficulties, but meeting them fully before grappling with them.

Had still greater dependence been placed on engineers and their advice been more strictly followed, some difficulties might have been avoided altogether or better preparation made to safely and successfully grapple with them.

Mr. F. Collingwood.—Do I understand the gentleman to say that this plan will be practical.

Mr. Wm. H. Paine.—I have not endorsed the plans that are now being carried out and that is the reason why I left the tunnel a long time since.